US009437406B2

(12) **United States Patent**
Ishizu et al.

(10) **Patent No.: US 9,437,406 B2**
(45) **Date of Patent: Sep. 6, 2016**

(54) **PHOTOMULTIPLIER AND SENSOR MODULE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/572,926**

(22) Filed: **Dec. 17, 2014**

(65) **Prior Publication Data**

US 2015/0187551 A1 Jul. 2, 2015

Related U.S. Application Data

(60) Provisional application No. 61/921,119, filed on Dec. 27, 2013.

(51) **Int. Cl.**
H01J 43/28 (2006.01)

(52) **U.S. Cl.**
CPC ***H01J 43/28*** (2013.01)

(58) **Field of Classification Search**
CPC H01J 43/04–43/28
See application file for complete search history.

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(57) **ABSTRACT**

A photomultiplier according to an embodiment of the present invention has a sealed container the interior of which is maintained in a vacuum state, and an electron multiplier unit housed in the sealed container, and the sealed container is partly constructed of ceramic side tubes, on the assumption that the photomultiplier is used under high-temperature, high-pressure environments. The photomultiplier further has a structure for fixing an installation position of the electron multiplier unit relative to the sealed container, for improvement in anti-vibration performance.

8 Claims, 16 Drawing Sheets

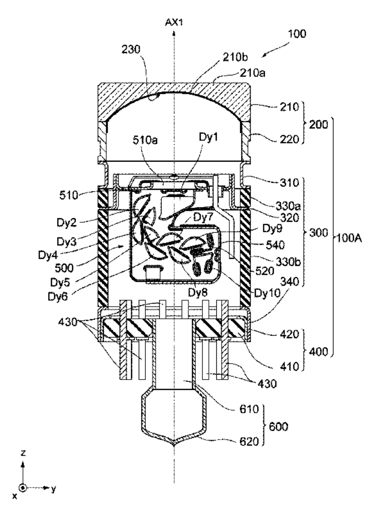

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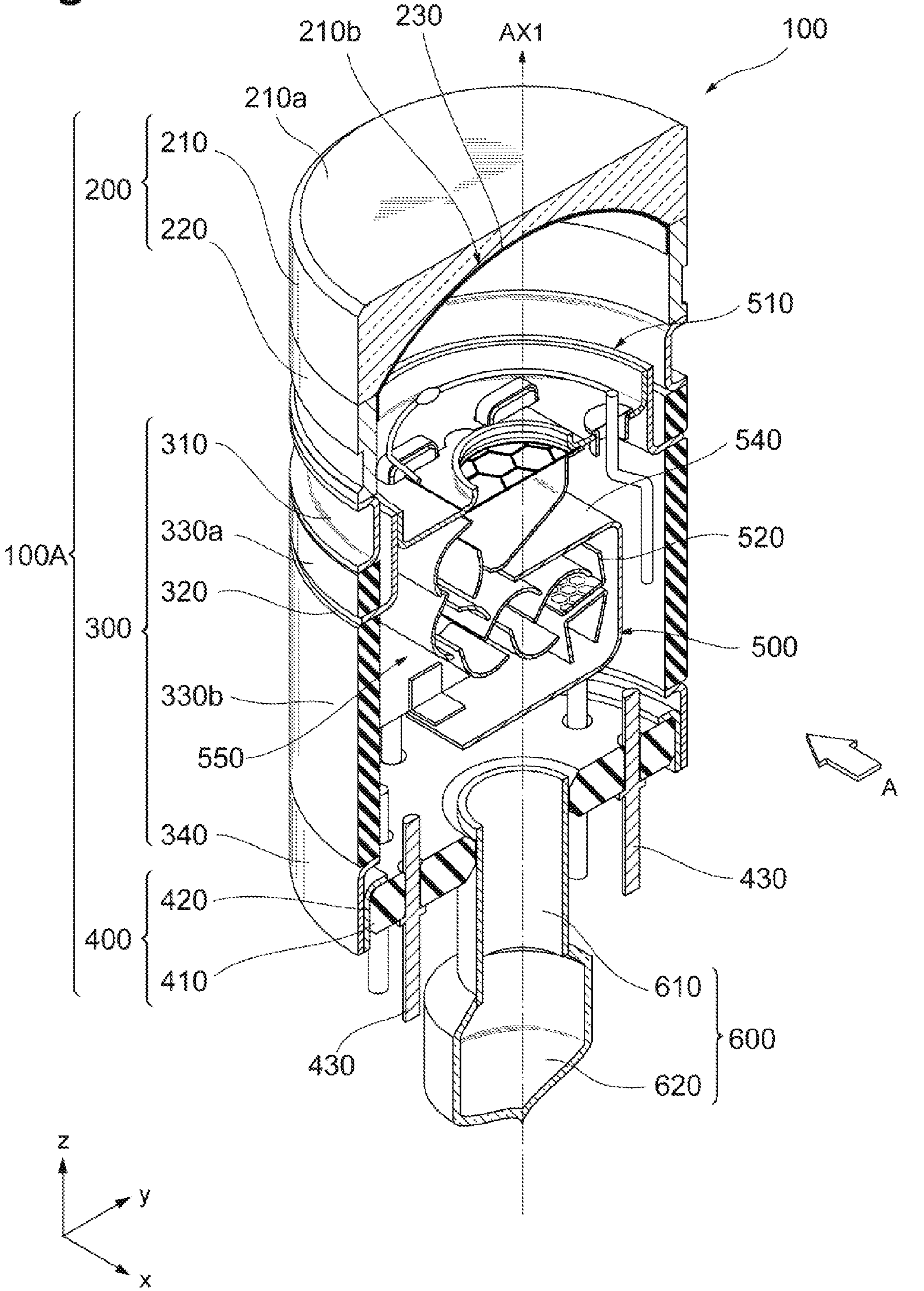
Fig.1



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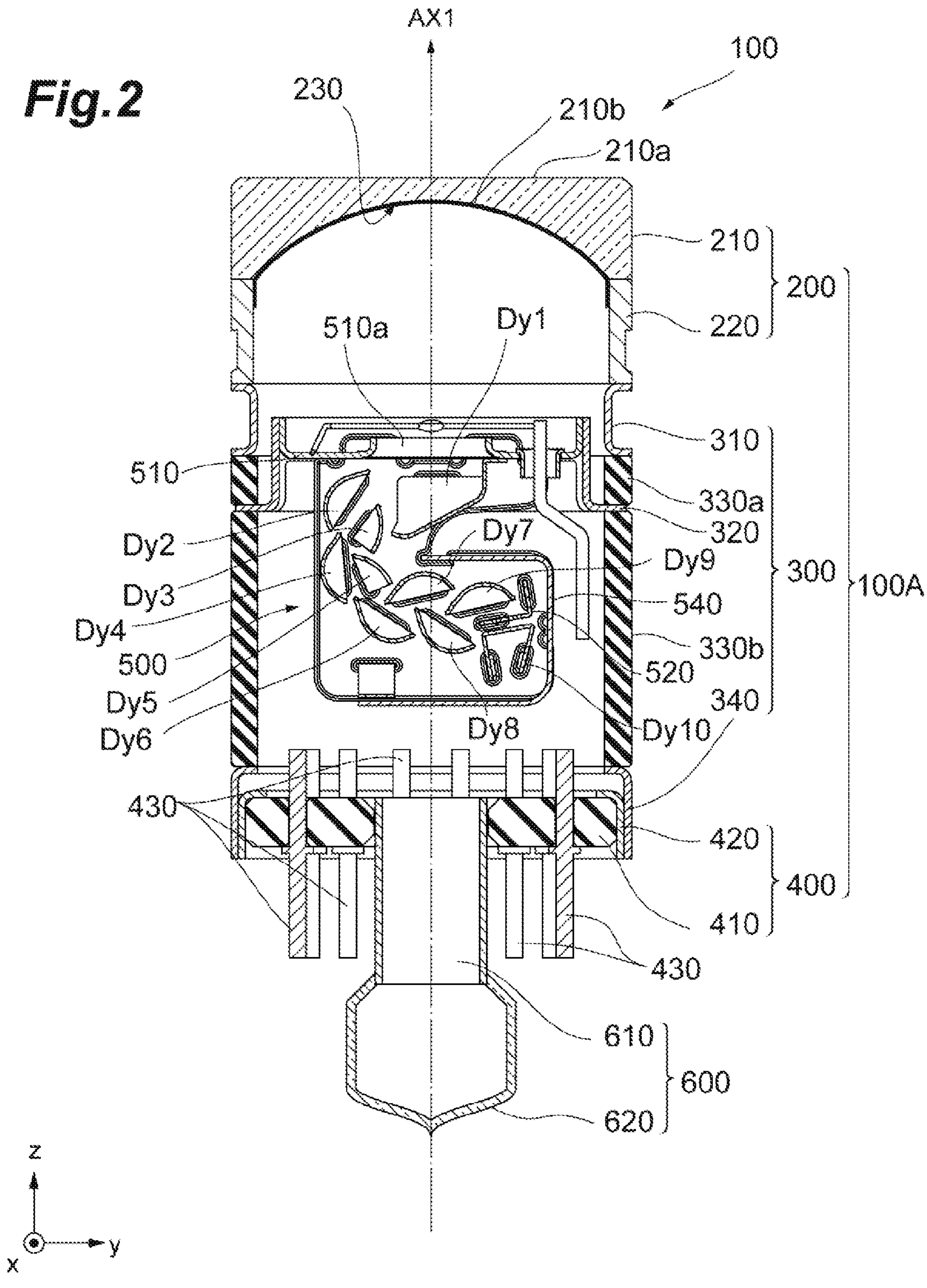
210b
AX1
100
210a
210
200
220
510
310
540
330a
520
100A
320
300
500
330b
550
A
340
430
420
400
410
610
600
430
620
z
y
x

Fig.2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Dy3
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540
Dy4
330b
500
520
Dy5
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Dy6
Dy8
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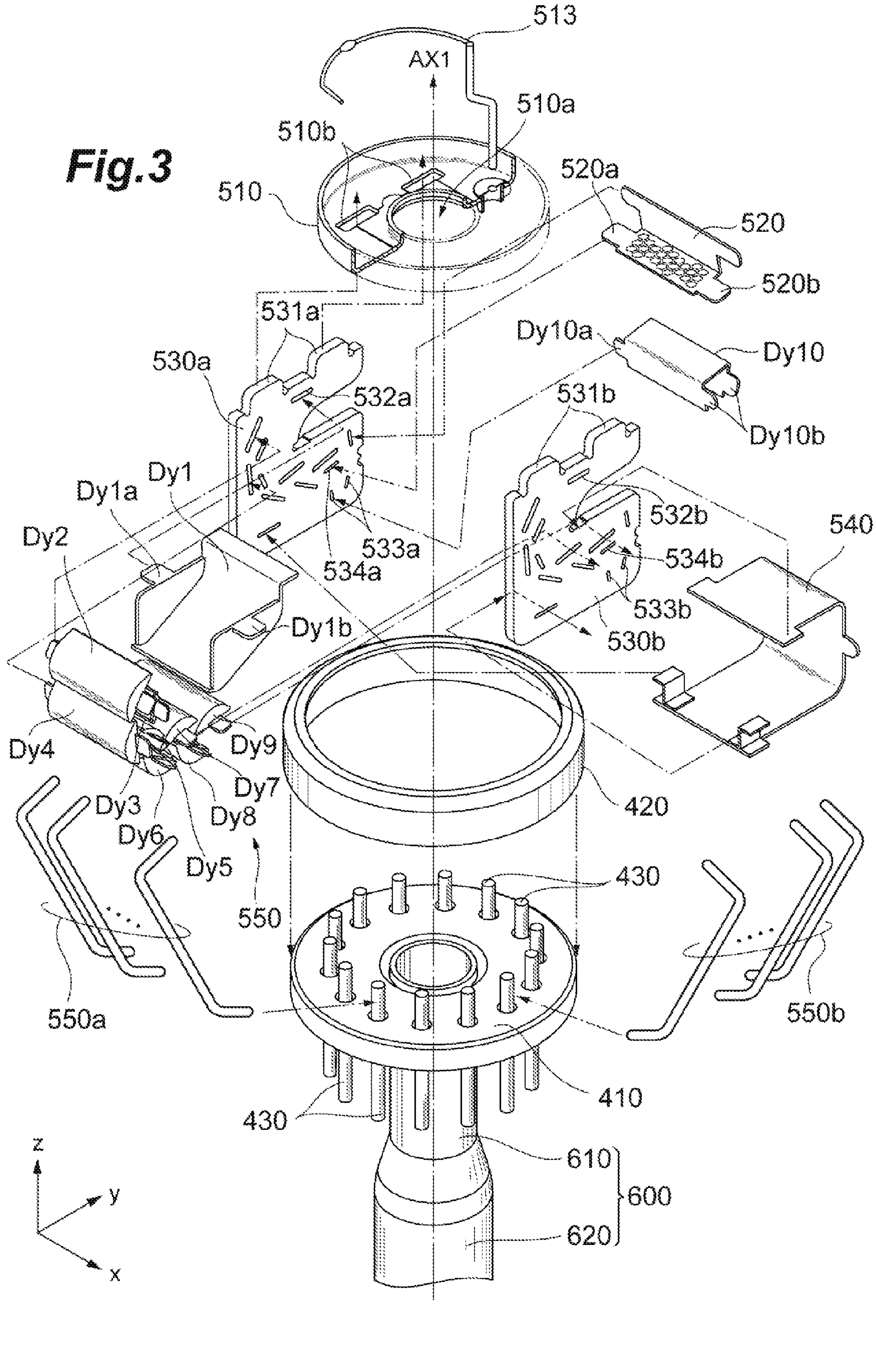
y
x

Fig.3



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Dy1a
532b
Dy2
533a
540
534a
534b
533b
Dy1b
530b
Dy9
Dy4
Dy7
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Fig.4

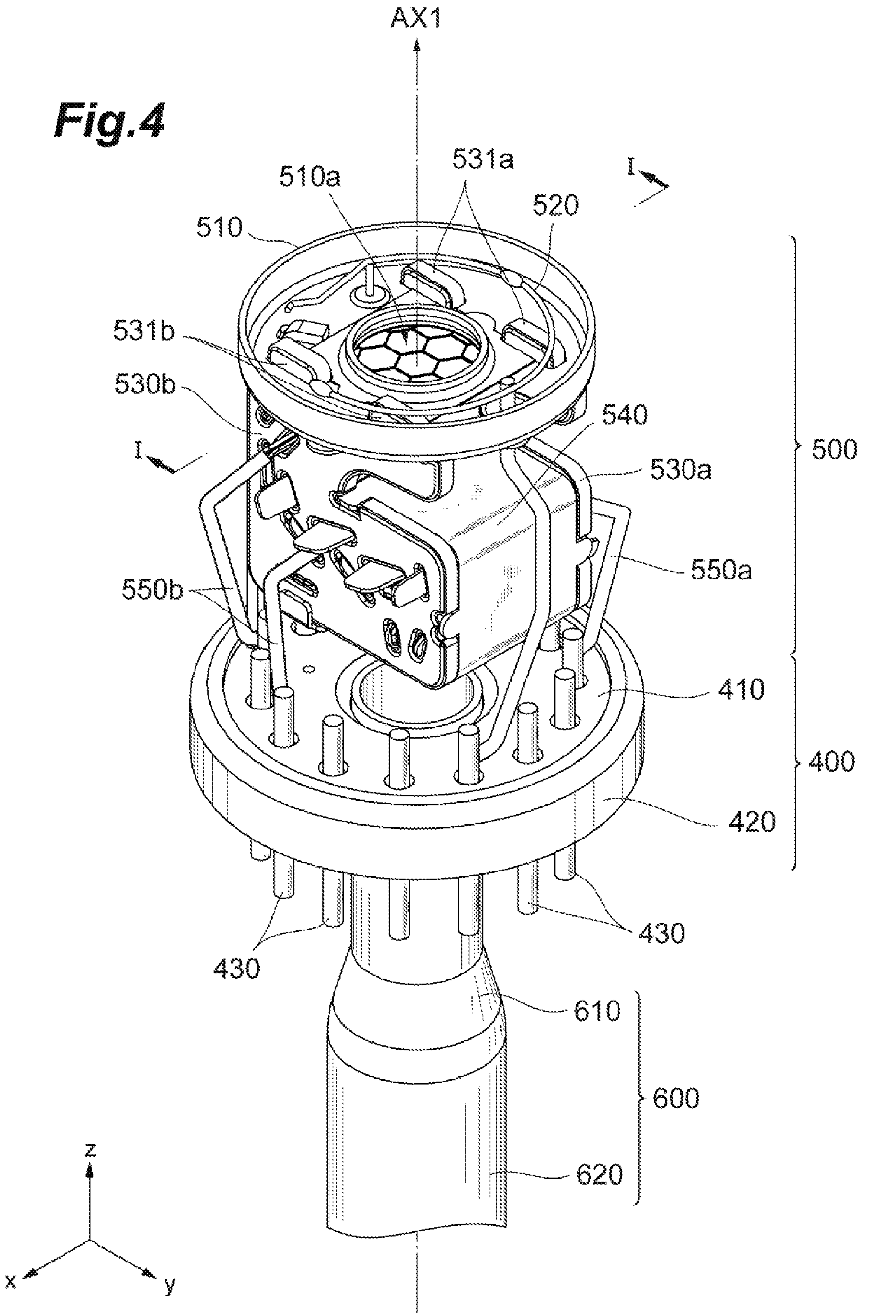
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Fig.5

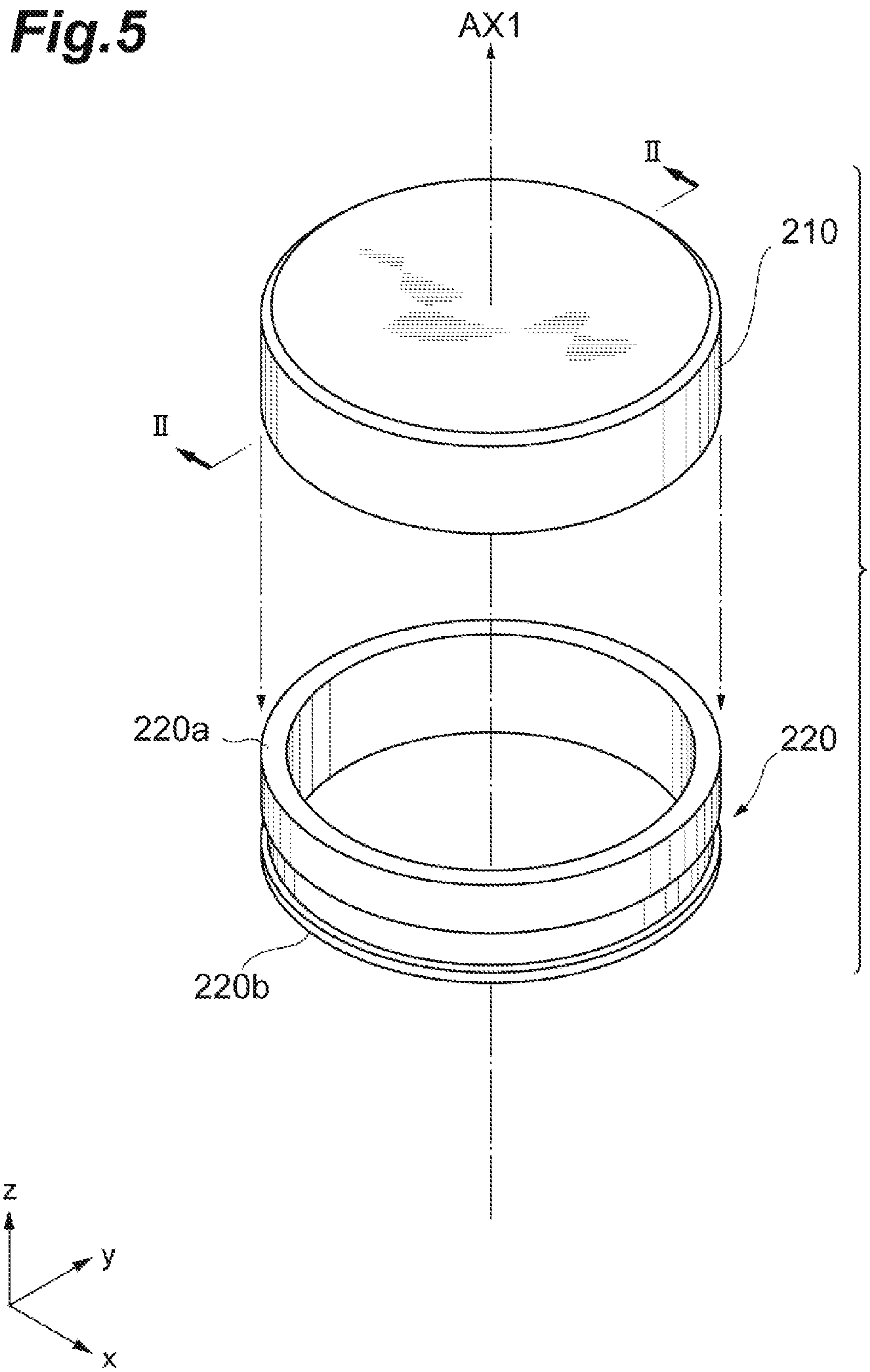

Fig.6

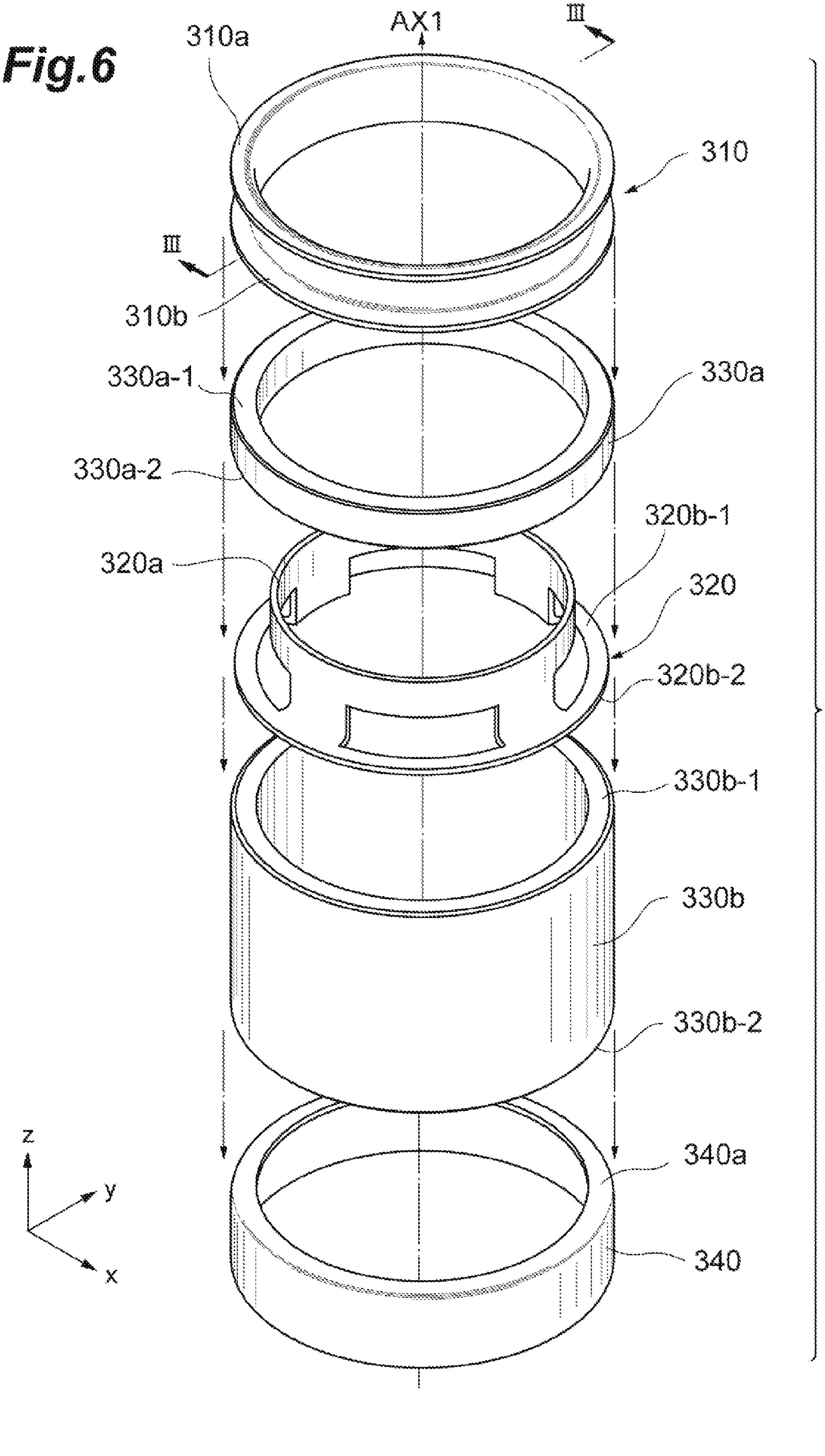
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Fig.7

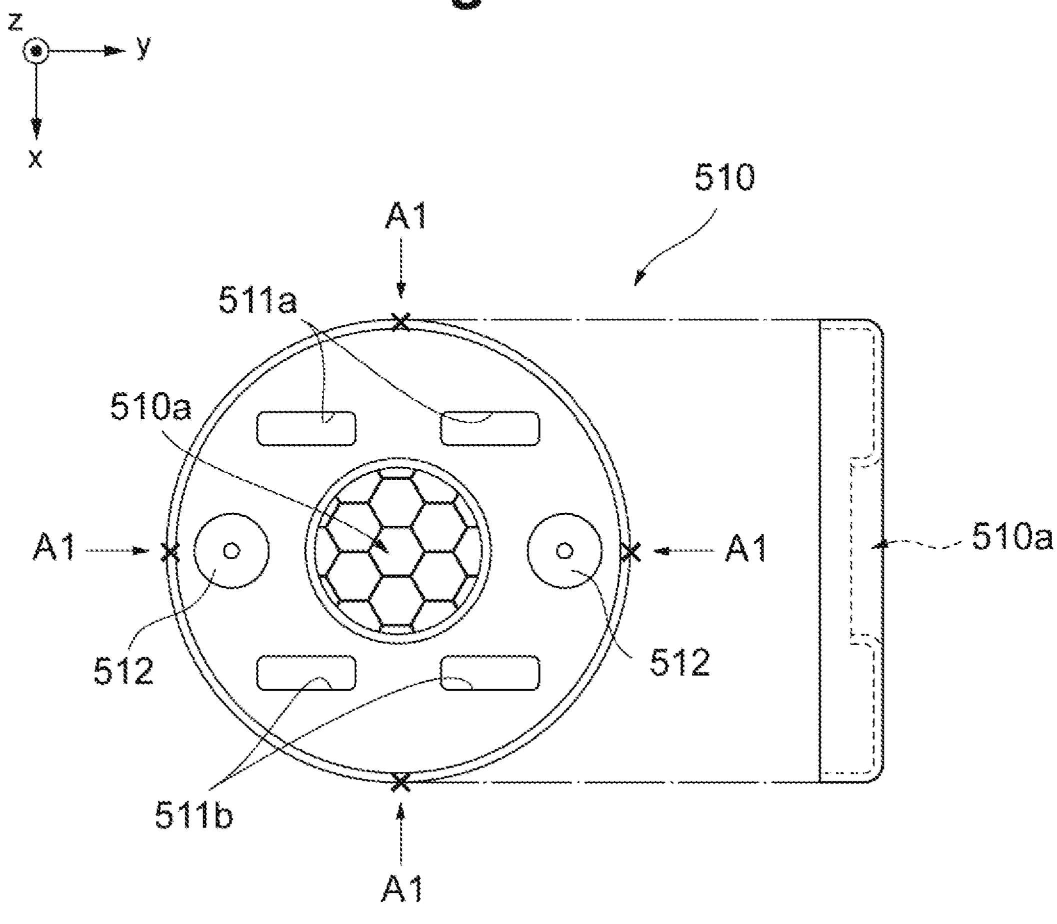

Fig.8

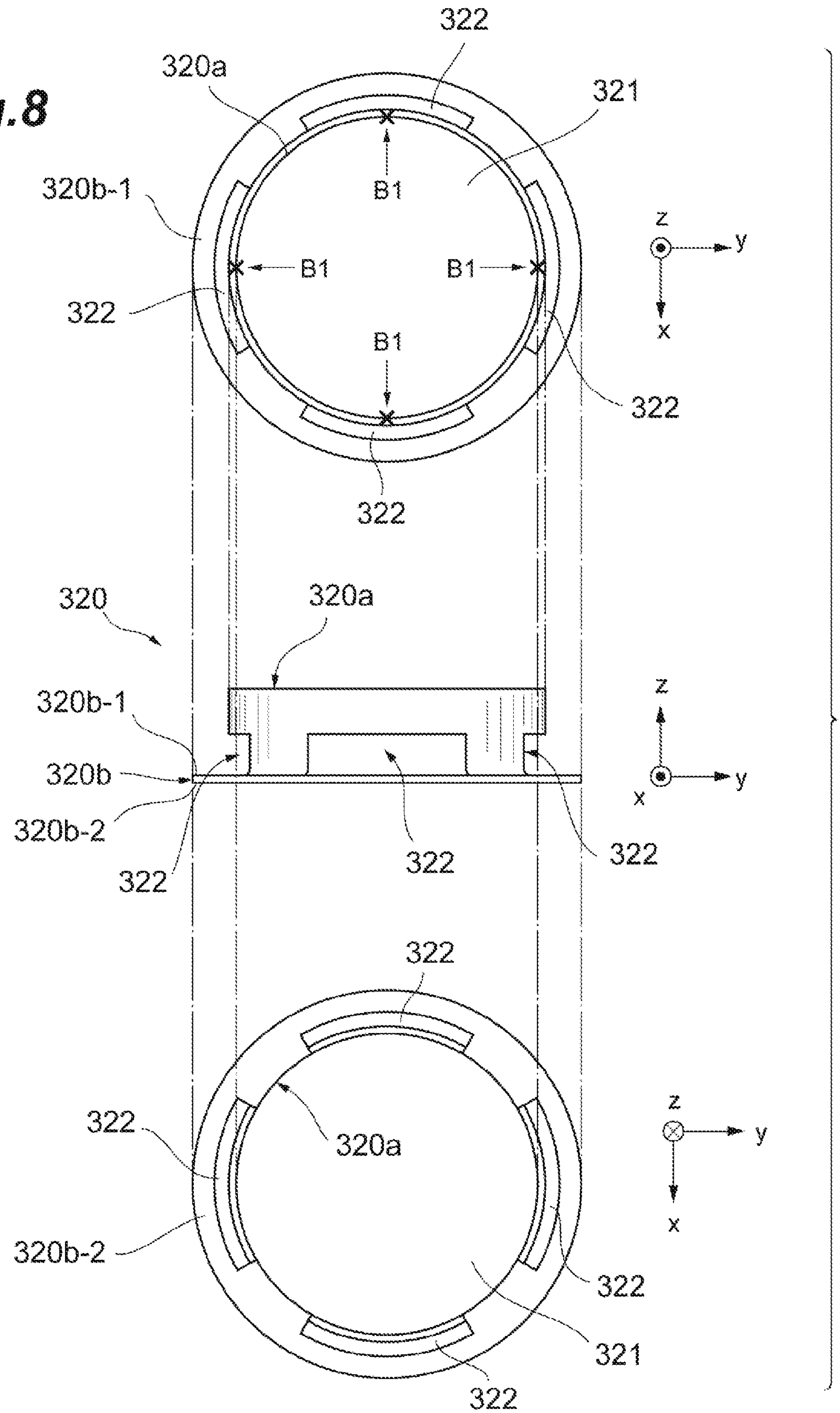

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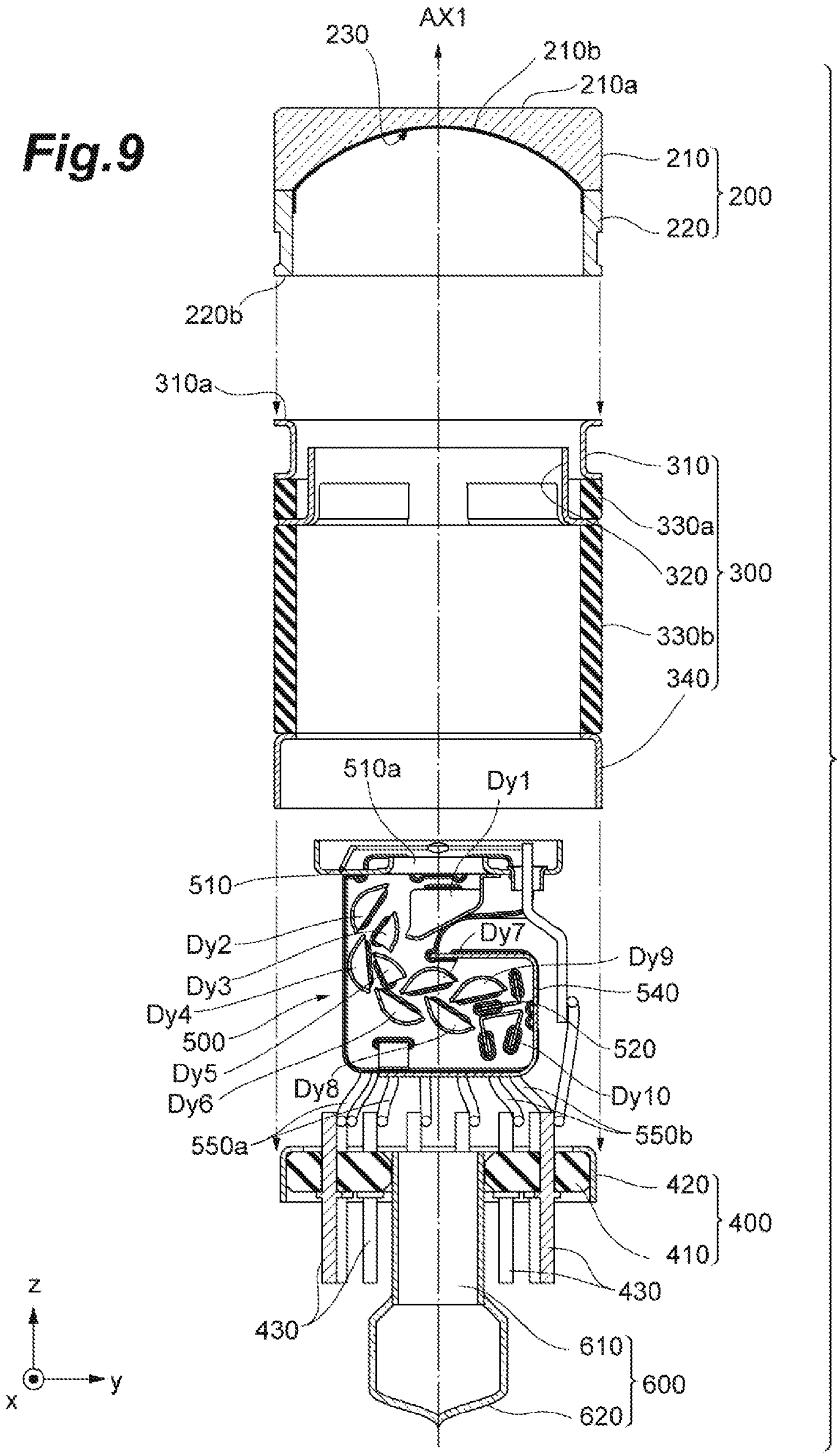
Fig.9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500
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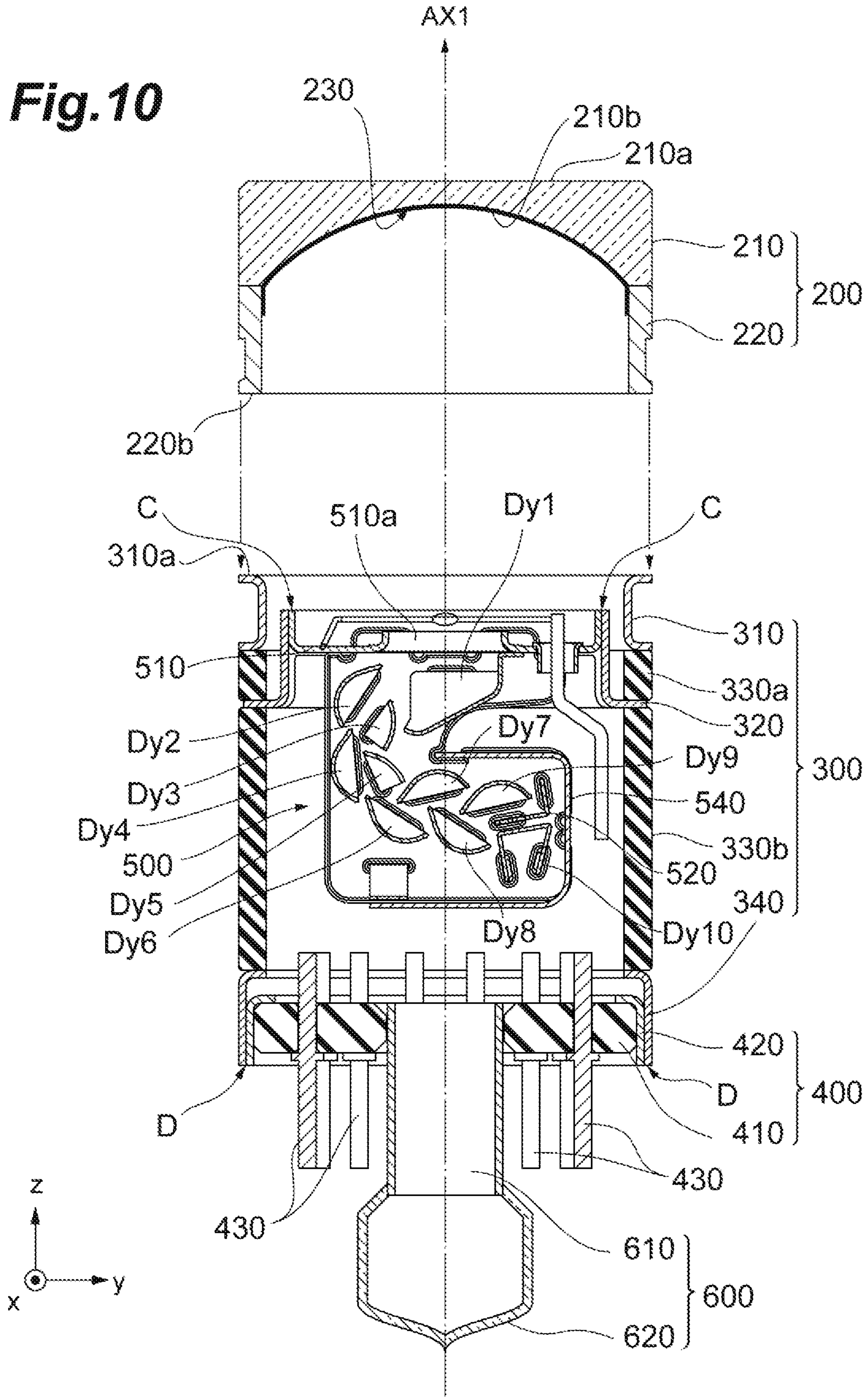
x

Fig.10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500
520
Dy5
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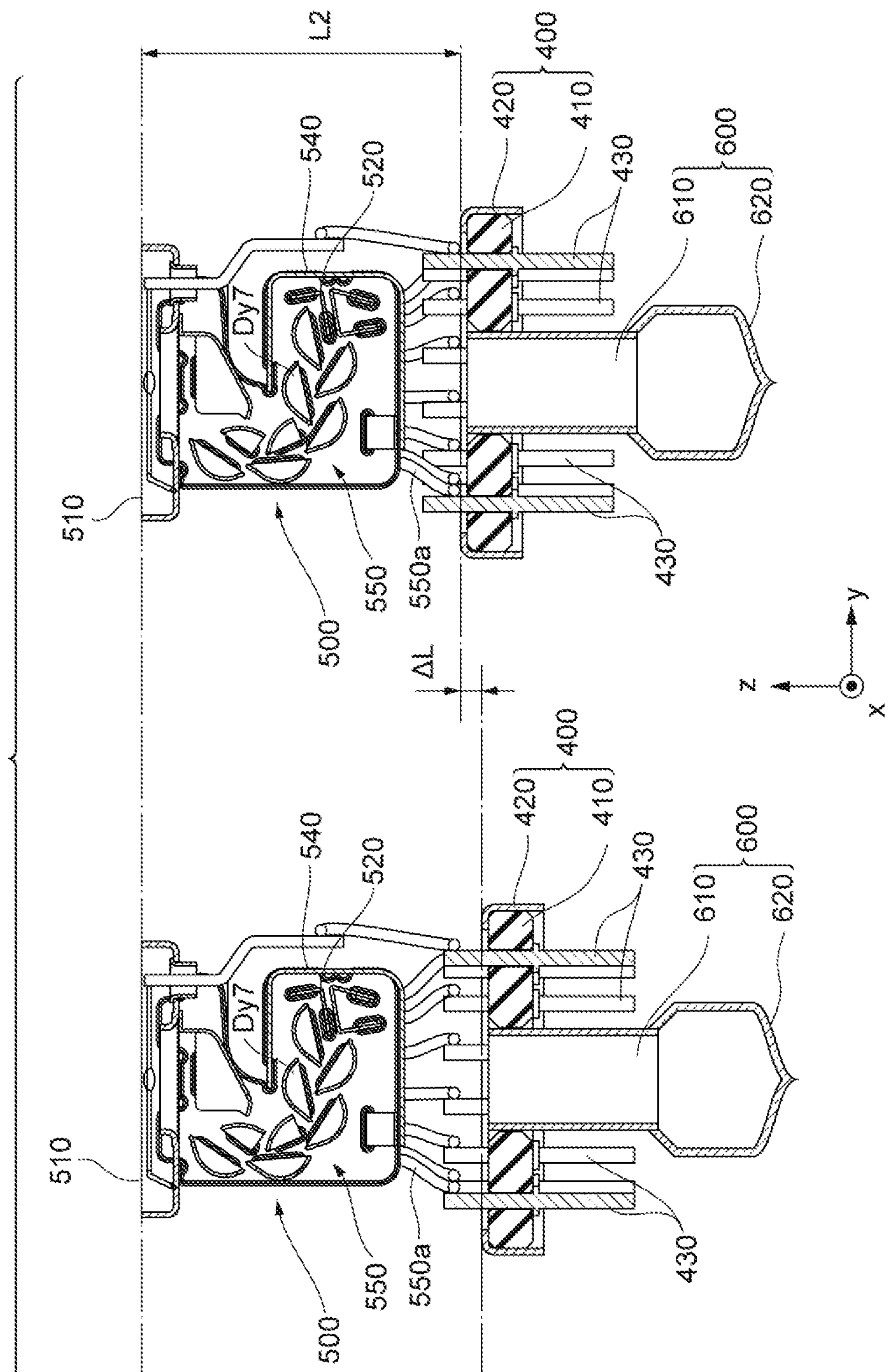
Fig.11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550a
430
ΔL
z
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520
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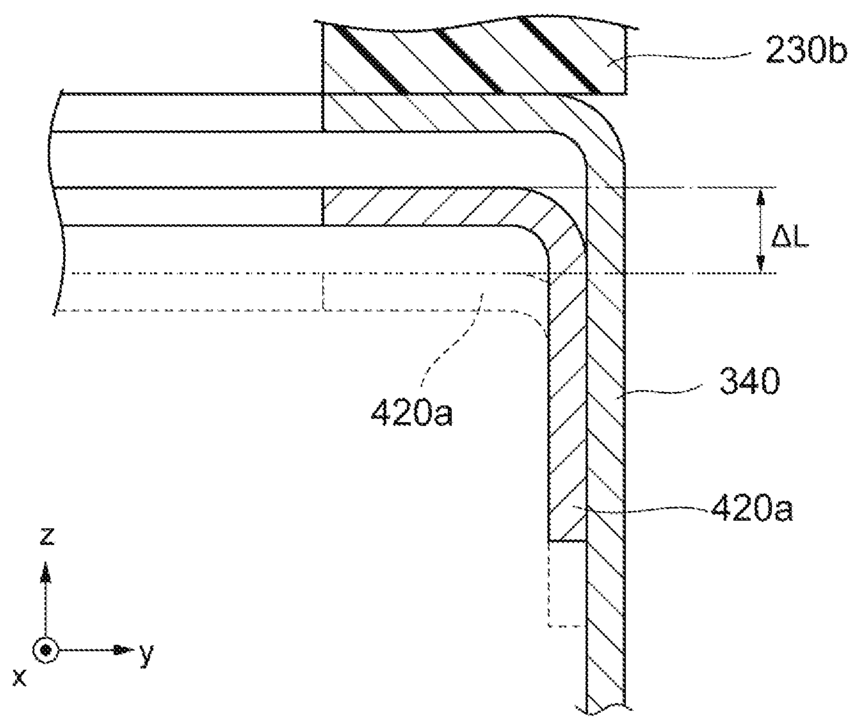
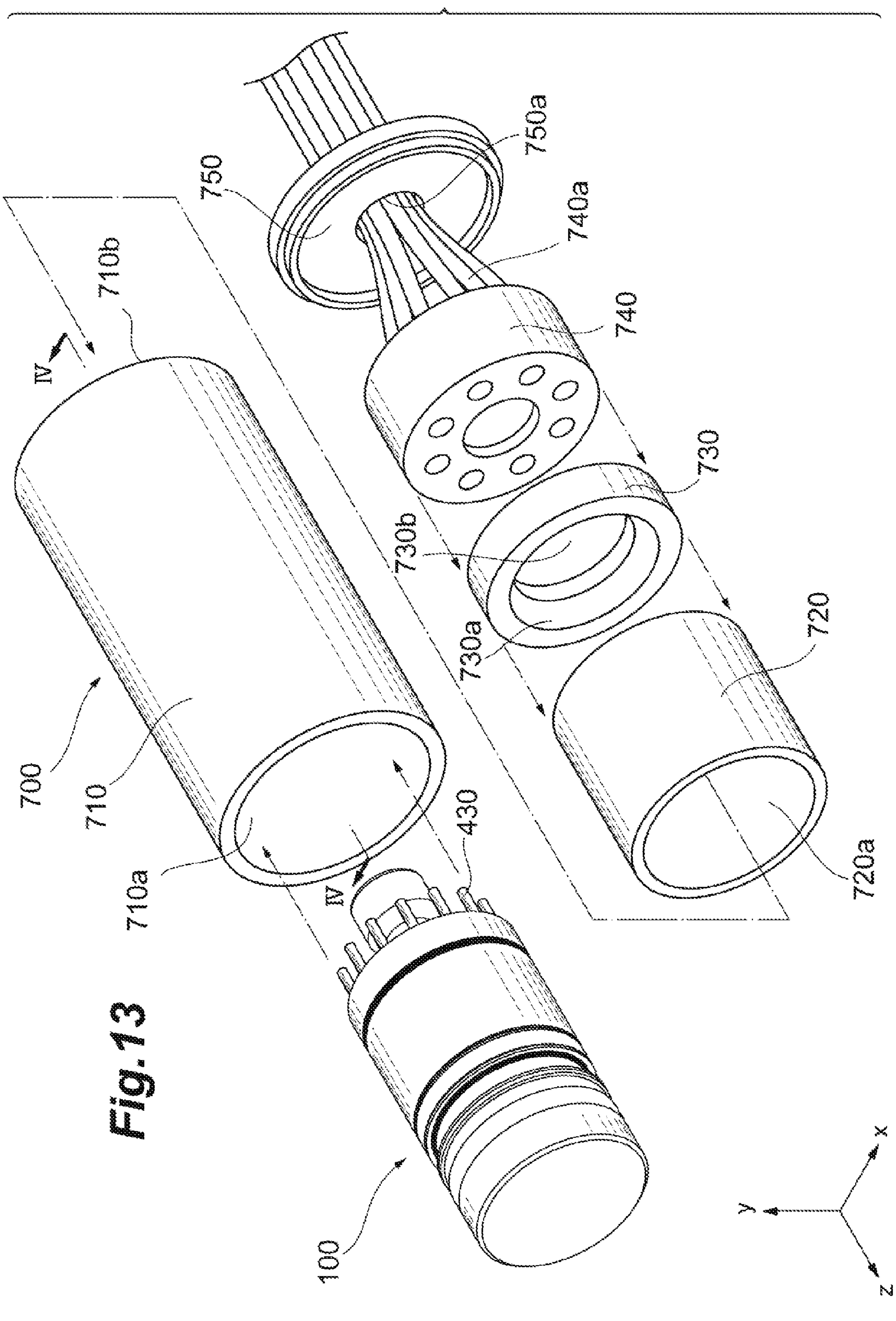
600
610
620
Dy7
510
500
550
550a
430
L1

Fig.12




700
710
710a
710b
IV
IV
720
720a
730
730a
730b
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740a
750
750a
430
100
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y
z

Fig.13

Fig.14

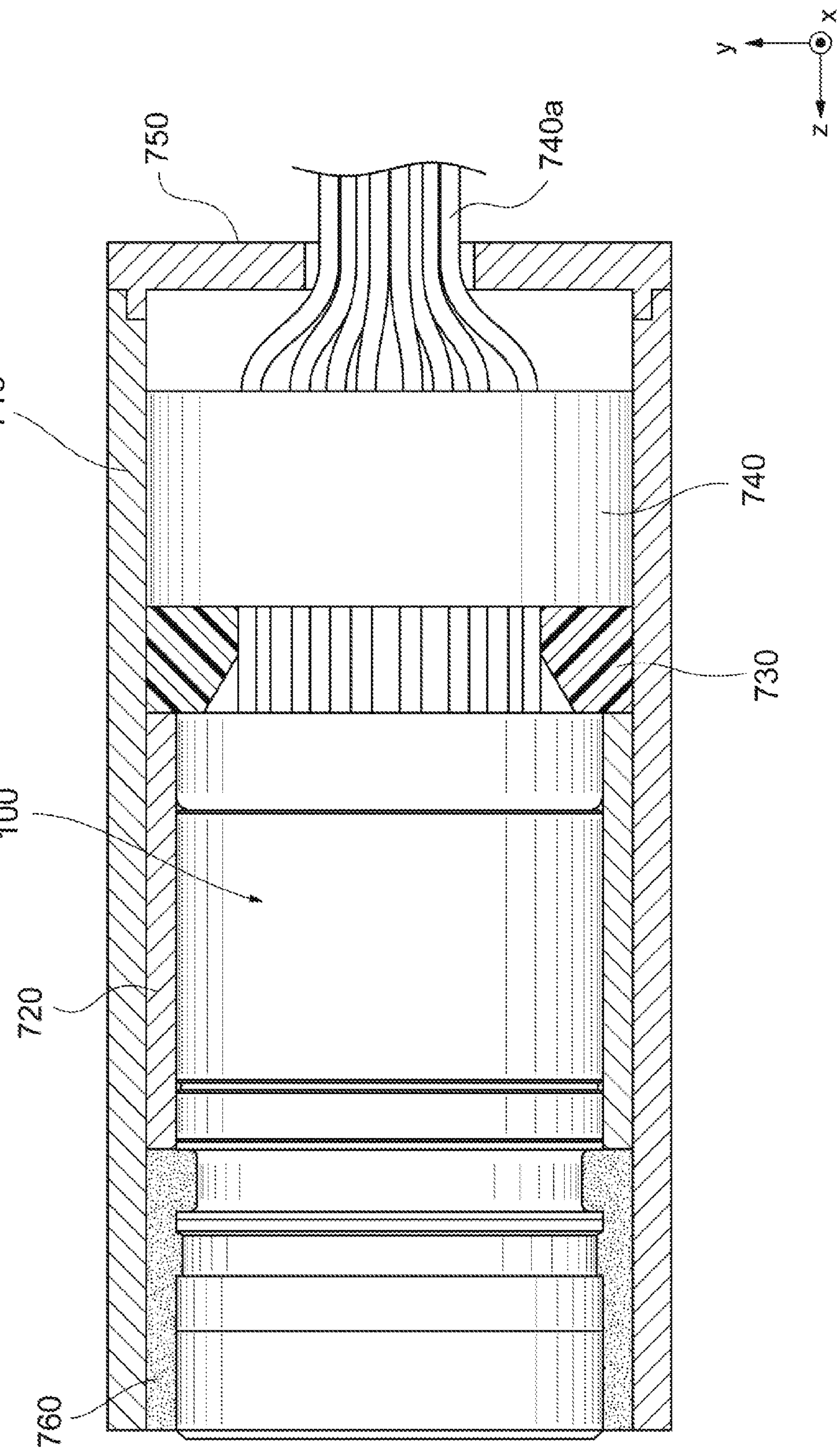


Fig.15

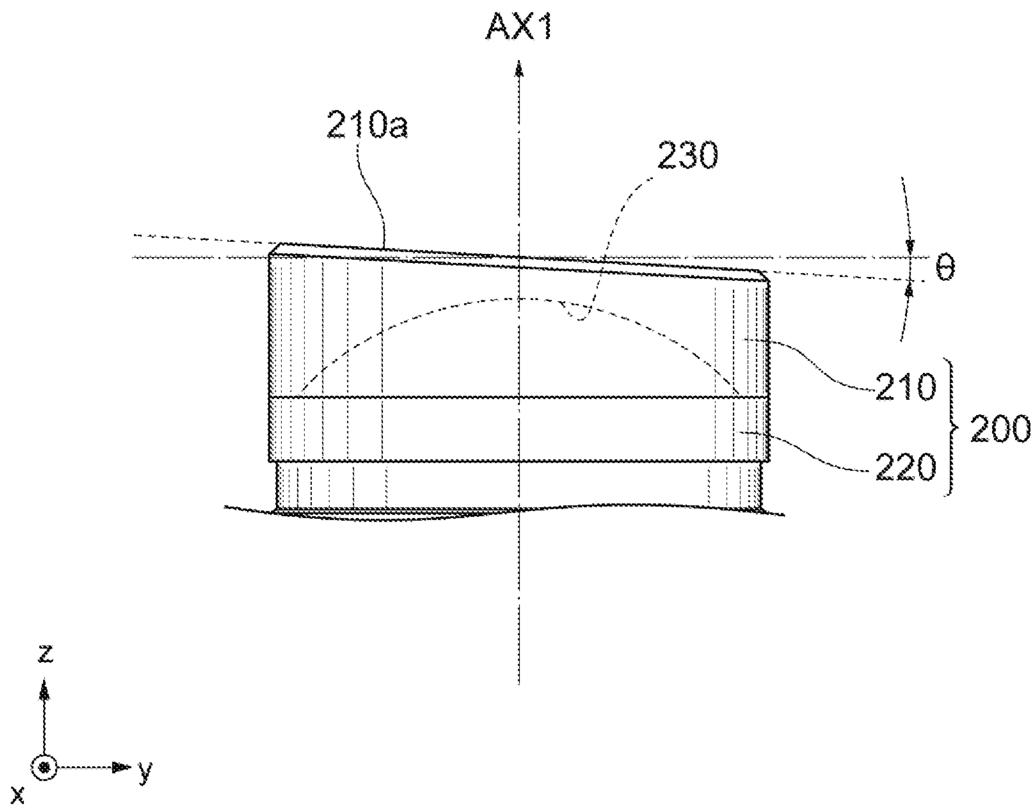
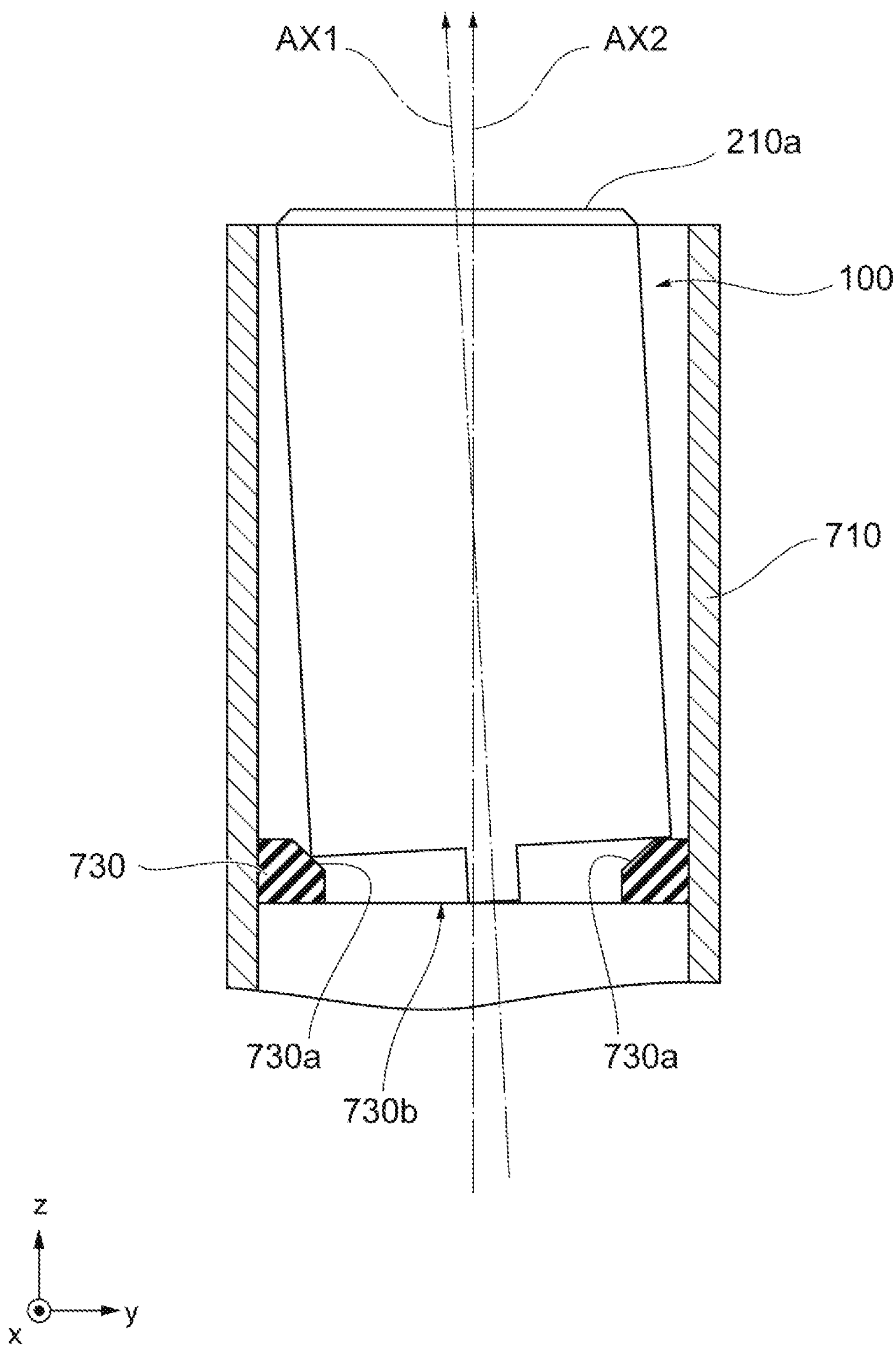


Fig.16



PHOTOMULTIPLIER AND SENSOR MODULE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a photomultiplier and a sensor module including the same.

2. Related Background Art

Japanese Patent No. 4640881 (Japanese Patent Application Laid-Open Publication No. 2002-42719) discloses a photomultiplier having a glass container the interior of which is maintained in a vacuum state, and an electron multiplier unit housed in the glass container. In this photomultiplier, the electron multiplier unit is held at a predetermined position in the glass container in a state in which it is supported by lead pins extending from a bottom (stem) of the glass container.

SUMMARY OF THE INVENTION

The Inventors examined the conventional photomultiplier and found the problem as described below. Specifically, in the conventional photomultiplier the relative position of the electron multiplier unit to the glass container is maintained by only the lead pins extending from stem pins. For this reason, when we assume that the photomultiplier is used under severe environments, e.g., in underground resource exploration, the conventional photomultiplier had a possibility of failing to maintain sufficient durability and high reliability.

For example, when the photomultiplier is assumed to be used in a high-temperature, high-pressure environment, the glass container can possibly fail to provide sufficient durability. In addition, the position of the electron multiplier unit relative to the glass container varies with intense vibration in the structure where the electron multiplier unit is held at the predetermined position in the glass container, and thus the reliability can also possibly degrade. Particularly, in the ordinary configuration wherein the glass container and a part of the electron multiplier unit are held by springs on the inner wall of the glass container, if unwanted gas is produced in the glass container because of friction by vibration, the photomultiplier will inevitably undergo degradation of reliability (reduction in measurement sensitivity, malfunction, and so on).

The present invention has been accomplished in order to solve the problem as described above and it is an object of the present invention to provide a photomultiplier capable of maintaining excellent durability and reliability even in the use under high-temperature, high-pressure environments and, particularly, to provide a photomultiplier with a structure for improvement in anti-vibration performance when compared with the conventional technology and a sensor module including the photomultiplier.

In order to solve the above-described problem, a photomultiplier according to an embodiment of the present invention, as a first aspect, comprises: a sealed container the interior of which is maintained in a predetermined vacuum state; a photocathode housed in the sealed container and configured to emit photoelectrons into the sealed container in response to light of a predetermined wavelength; an electron multiplier unit housed in the sealed container; and a structure for fixing an installation position of the electron multiplier unit in the sealed container. It is noted that in the present specification the vacuum state refers to a state achieved by evacuating gas in the sealed container by means of a vacuum pump or the like, in which the degree of vacuum represented by pressure of residual gas in the sealed container is maintained at 10^{-1} Pa or less (note: the artificially possible pressure at present is approximately 10^{-10} Pa).

In the foregoing first aspect, the sealed container includes a first ceramic side tube and a second ceramic side tube arranged in order along a first tube axis of the sealed container, on the assumption of use under high-temperature, high-pressure environments. The electron multiplier unit is comprised of a dynode unit, an anode, a pair of insulating support members integrally grasping these dynode unit and anode, and a focusing electrode fixed to the pair of insulating support members. The dynode unit includes multi-stage dynodes for emitting secondary electrons in response to the photoelectrons arriving from the photocathode and successively cascade-multiplying the emitted secondary electrons. The anode extracts secondary electrons resulting from the cascade multiplication by the dynode unit, as a signal. The focusing electrode is disposed between the photocathode and the dynode unit in a state in which it is fixed to the pair of insulating support members. Furthermore, the focusing electrode has a through hole for letting the photoelectrons from the photocathode pass through.

The structure for fixing the installation position of the electron multiplier unit in the sealed container is realized by a fixing member forming a part of the sealed container. Specifically, the fixing member has an aperture for defining an installation position of the focusing electrode, an inside end defining the aperture, and an outside end surrounding the inside end. Furthermore, the outside end is grasped by the first ceramic side tube and the second ceramic side tube whereby the fixing member is fixed to the sealed container. On the other hand, the inside end of the fixing member located in the sealed container is fixed to the focusing electrode. This configuration fixes the installation position of the electron multiplier unit relative to the sealed container, thereby to achieve drastic improvement in anti-vibration performance of the photomultiplier.

As a second aspect applicable to the first aspect, the sealed container may further comprise a stem portion, and a metal side tube for defining an installation position of the stem portion. Specifically, the stem portion is comprised of a ceramic pedestal for, with a plurality of stem pins penetrating through, holding these stem pins, and a metal reinforcement member covering at least a side face of the ceramic pedestal. Furthermore, the metal side tube is located opposite to the first ceramic side tube with the second ceramic side tube in between, and one end thereof is fixed to the second ceramic side tube. In this configuration, the metal reinforcement member of the stem portion is fixed to the metal side tube.

As a third aspect applicable to at least either one of the first and second aspects, the fixing member may have a plurality of through holes provided between the inside end and the outside end. Each of these through holes establishes communication between a space where the dynode unit exists and a space where the photocathode exists. The luminescent phenomenon occurs in the anode with increase in electron density and light from the anode, if reaching the photocathode, would be reflected as noise component in the signal extracted from the anode. On the other hand, the photocathode is formed by supplying an alkali metal vapor from the stem portion side toward the photocathode side and, for this reason, a gap in some width is needed between the side tubes and the electron multiplier unit inside the sealed container in the vacuum state. In the third aspect, therefore, a light shield function is realized by the fixing member with the inside end located inside the sealed container and the outer peripheral portion of the focusing electrode, while a flow path for the alkali metal vapor is secured by the plurality of through holes provided in the fixing member. As a fourth aspect applicable to the third aspect, the plurality of through holes in the fixing member are preferably arranged so as to surround the first tube axis of the sealed container.

The photomultiplier according to at least any one of the first to fourth aspects can be applied to a sensor module used under high-temperature, high-pressure environments, for example, in underground resource exploration.

Specifically, as a fifth aspect, a sensor module according to an embodiment of the present invention comprises: the photomultiplier having the structure as described above (the photomultiplier according to the embodiment of the present invention); and a case for housing the photomultiplier. The case of the sensor module has openings at two ends thereof and has a shape extending along a second tube axis.

As a sixth aspect applicable to the fifth aspect, the sensor module may further comprise a positioning spacer for defining an installation position of the photomultiplier in the case, the positioning spacer being installed in the case. Furthermore, as a seventh aspect applicable to the sixth aspect, the positioning spacer preferably has a taper face with which a part of the photomultiplier is in contact. In this case, it becomes feasible to adjust a posture of the photomultiplier relative to the second tube axis of the case, in a state in which the stem portion of the photomultiplier is in contact with the positioning spacer (i.e., in a state in which posture stability of the photomultiplier in the case is ensured). Specifically, as an eighth aspect applicable to at least either one of the sixth and seventh aspects, the photomultiplier can be stably kept and fixed in the case, even in a state in which the first tube axis of the sealed container and the second tube axis of the case are out of alignment.

Each of embodiments according to this invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings. These embodiments are given by way of illustration only, and thus are not to be considered as limiting the present invention.

Further scope of applicability of this invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, and it is apparent that various modifications and improvements within the spirit and scope of the invention will be obvious to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partly broken view showing an internal structure of a photomultiplier according to an embodiment of the present invention.

FIG. **2** is a drawing showing a cross-sectional structure of the photomultiplier according to the embodiment of the present invention, which is a view from a direction indicated by an arrow A in FIG. **1**.

FIG. **3** is an assembly process diagram of an electron multiplier unit installed in a sealed container of the photomultiplier according to the embodiment of the present invention.

FIG. **4** is a perspective view of the electron multiplier unit obtained through the assembly process shown in FIG. **3**.

FIG. **5** is an assembly process diagram of a head portion forming a part of the sealed container in the photomultiplier according to the embodiment of the present invention.

FIG. **6** is an assembly process diagram of a body portion forming a part of the sealed container in the photomultiplier according to the embodiment of the present invention.

FIG. **7** is a development diagram showing a structure of a focusing electrode disc forming a part of the electron multiplier unit.

FIG. **8** is a development diagram showing a structure of a fixing member (fixing metal flange) for fixing the electron multiplier unit.

FIG. **9** is a drawing (part 1) for explaining a final assembly process of the photomultiplier according to the embodiment of the present invention, which is a cross-sectional view coincident with a cross section of the electron multiplier unit along the line I-I in FIG. **4**, a cross section of the head portion along the line II-II in FIG. **5**, and a cross section of the body portion along the line III-III in FIG. **6**.

FIG. **10** is a drawing (part 2) for explaining the final assembly process of the photomultiplier according to the embodiment of the present invention, which is a cross-sectional view coincident with the cross section of the electron multiplier unit along the line I-I in FIG. **4**, the cross section of the head portion along the line II-II in FIG. **5**, and the cross section of the body portion along the line III-III in FIG. **6**.

FIG. **11** is a drawing for explaining the technical effect of the stem portion in the photomultiplier according to the embodiment of the present invention.

FIG. **12** is a drawing for explaining an assembly process of the stem portion in the photomultiplier according to the embodiment of the present invention.

FIG. **13** is a drawing for explaining an assembly process of a sensor module according to the embodiment of the present invention.

FIG. **14** is a drawing showing a cross-sectional structure along the line IV-IV in FIG. **13**, of the sensor module according to the embodiment of the present invention.

FIG. **15** is a drawing for explaining a relationship between a first tube axis of the photomultiplier according to the embodiment of the present invention and a light entrance face of a glass faceplate forming a part of the head portion in the photomultiplier.

FIG. **16** is a drawing for explaining the technical effect of the sensor module according to the embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

Various embodiments of the photomultiplier and sensor module according to the present invention will be described below in detail with reference to the accompanying drawings. In the description of the drawings the same portions and the same elements will be denoted by the same reference signs, without redundant description.

FIG. **1** is a partly broken view showing an internal structure of a photomultiplier according to an embodiment of the present invention, and FIG. **2** a drawing showing a cross-sectional structure of the photomultiplier according to the embodiment of the present invention, which is a view from a direction indicated by an arrow A in FIG. **1**.

As shown in FIG. **1**, the photomultiplier **100** has a sealed container **100**A to a bottom part of which an exhaust tube **600** (a glass part of which is sealed after evacuation) for evacuating the interior is attached, and also has a photocathode **230** and an electron multiplier unit **500** provided in this sealed container **100**A.

The sealed container **100**A is composed of a head portion **200**, a body portion **300**, and a stem portion **400** arranged along a tube axis AX1 (first tube axis) thereof. The head portion **200** is composed of a glass faceplate **210** having a light entrance face **210***a* and a back face **210***b* opposed to the light entrance face **210***a*, and a Kovar flange **220**. The back face **210***b* of the glass faceplate **210** is a curved surface defining an interior space of the sealed container **100**A and the photocathode **230** is provided on this back face **210***b*. The body portion **300** is composed of a Kovar flange **310**, a first ceramic side tube **330***a*, a fixing metal flange **320**, a second ceramic side tube **330***b*, and a metal side tube **340**, which are arranged in order from the head portion **200** toward the stem portion **400** along the first tube axis AX1. The stem portion **400** is fixed to the metal side tube **340** in a state in which at least a part thereof is housed in the metal side tube **340**. Furthermore, the stem portion **400** is composed of a ceramic pedestal **410** holding a plurality of stem pins **430** in a state in which the stem pins **430** penetrate through, and a metal reinforcement member **420** for protecting the side face of the ceramic pedestal **410**. A plurality of electrodes forming the electron multiplier unit **500** (including a dynode unit and an anode) are electrically connected through a plurality of connection pins (lead pins) corresponding to the respective electrodes, to a plurality of stem pins **430** fixed to the ceramic pedestal **410**. By this configuration, the electron multiplier unit **500** is held at a predetermined position in the sealed container **100**A, in a state in which it is supported by the connection pins extending from the respective stem pins **430**.

The exhaust tube **600** extending along the first tube axis AX1 is fixed to the center of the ceramic pedestal **410**. The exhaust tube **600** is composed of a metal pipe **610** one end of which is brazed to the ceramic pedestal **410** with an Ag—Cu alloy, and a glass pipe **620** fixed to the other end of the metal pipe **610**. The glass pipe **620** is collapsed after evacuation of the interior of the sealed container **100**A, whereby the interior of the sealed container is maintained in a constant degree of vacuum. Furthermore, the sealed container **100**A shown in FIGS. **1** and **2** has a hollow cylindrical shape, but its sectional shape (shape defined by a shape on a plane perpendicular to the first tube axis AX1) does not always have to be limited to a circle.

The electron multiplier unit **500** is composed of a focusing electrode disc **510**, a dynode unit **550**, and an anode **520** arranged inside the dynode unit **550**. The focusing electrode disc **510** is an electrode for altering the trajectory of photoelectrons emitted from the photocathode **230**, so as to focus them toward the dynode unit **550**, which is arranged between the photocathode **230** and the dynode unit **550** and which has a through hole **510***a* for letting the photoelectrons from the photocathode **230** pass through. The dynode unit **550** is composed of multi-stage dynodes Dy**1** to Dy**10** for successively cascade-multiplying secondary electrons emitted in response to the photoelectrons arriving via the focusing electrode disc **510** from the photocathode **230**. In addition, the electron multiplier unit **500** further has a pair of insulating support members **530***a*, **530***b* for integrally grasping the focusing electrode disc **510**, the dynode unit **550** composed of the multi-stage dynodes Dy**1**-Dy**10**, and the anode **520** for extracting secondary electrons resulting from the cascade multiplication by the multi-stage dynodes Dy**1**-Dy**9** and secondary electrons from the inverting dynode Dy**10** as a signal. The anode **520** is arranged on the trajectory of secondary electrons traveling from the ninth-stage dynode Dy**9** to the inverting dynode Dy**10**. In the dynode unit **550**, the inverting dynode Dy**10** is a dynode for receiving secondary electrons passing through the anode **520** among the secondary electrons emitted from the ninth-stage dynode Dy**9** and for again emitting secondary electrons toward the anode **520**.

The electron multiplier unit **550** housed in the sealed container **100**A is arranged, as shown in FIGS. **1** and **2**, so that the dynode unit **550** and the anode **520**, together with the focusing electrode disc **510**, are integrally held by the pair of insulating support members **530***a*, **530***b*. A light shield member **540** surrounding the anode **520** is also attached to the pair of insulating support members.

Furthermore, the photomultiplier **100** has the structure (the pair of insulating support members) for integrally holding at least the focusing electrode disc **510**, the dynode unit **550**, the anode **520**, and the light shield member **540**, in a state in which at least the first-stage dynode Dy**1** and the second-stage dynode Dy**2** in the dynode unit **550** are directly opposed to the focusing electrode disc **510** without any conductive member in between. As a result, variation in electron transit time is drastically reduced in a process of travel from the photocathode **230** via the first-stage dynode Dy**1** to the second-stage dynode Dy**2** because a metal disc set at the same potential as the first-stage dynode Dy**1** and directly supporting the first-stage dynode Dy**1** as in the conventional photomultiplier, is not interposed between the focusing electrode disc **510** and the dynode unit **550**.

Next, manufacturing processes of the respective parts in the photomultiplier **100** according to the present embodiment will be described in detail using FIGS. **3** to **10**. FIG. **3** is an assembly process diagram of the electron multiplier unit **500** installed in the sealed container **100**A of the photomultiplier **100** according to the present embodiment. FIG. **4** is a perspective view of the electron multiplier unit obtained through the assembly process shown in FIG. **3**.

As shown in FIG. **3**, the electron multiplier unit **500** includes the focusing electrode disc **510**, dynode unit **550**, and anode **520** as electrodes. The focusing electrode disc **510** is provided with the through hole **510***a* for letting the photoelectrons from the photocathode **230** pass through. The dynode unit **550** is composed of the first-stage to ninth-stage dynodes Dy**1**-Dy**9** and the inverting dynode Dy**10**, each of which is grasped by the first and second insulating support members **530***a*, **530***b*, and the anode **520** is arranged on the trajectory of secondary electrons between the ninth-stage dynode Dy**9** and the inverting dynode Dy**10**. Each of the first-stage to ninth-stage dynodes Dy**1**-Dy**9** and the inverting dynode Dy**10** has a reflective secondary electron emitting surface configured to receive photoelectrons or secondary electrons and emit new secondary electrons to a direction of incidence of the electrons. Furthermore, at the two ends of the first-stage dynode Dy**1** there are fixing pieces Dy**1***a*, Dy**1***b* provided so as to be grasped by the first and second insulating support members **530***a*, **530***b*. Similarly, each of the second-stage dynode Dy**2** to the ninth-stage dynode. Dy**9** and the inverting dynode Dy**10** is also provided with fixing pieces at two ends thereof. Let us describe an assembly process of the first-stage dynode Dy**1** as a representative. The fixing piece Dy**1***a* provided at one end of the first-stage dynode Dy**1** is inserted into an installation hole **532***a* of the first insulating support member **530***a* and a projecting portion thereof from the installation hole **532***a* is welded and fixed to a connection pin **550***a*. Furthermore, the fixing piece Dy**1***b* provided at the other end of the first-stage dynode Dy**1** is inserted into an installation hole **532***b* of the second insulating support member **530***b* and a projecting portion thereof from the installation hole **532***b* is welded and fixed to a connection pin **550***b*. In the present embodiment, the welding fixation is assumed to be implemented by laser welding. For each of the second- to ninth-stage dynodes Dy**2**-Dy**9**, a fixing piece provided at one end is also welded and fixed to a connection pin **550***a* while being inserted in a corresponding installation hole of the first insulating support member **530***a* and a fixing piece provided at the other end is welded and fixed to a connection pin **550***b* while being inserted in a corresponding installation hole of the second insulating support member **530***b*.

Furthermore, there are also fixing pieces **520***a*, **520***b* provided at two ends of the anode **520**, the fixing piece **520***a* is inserted into a corresponding installation hole **534***a* of the first insulating support member **530***a*, and a projecting portion thereof from the installation hole **534***a* is welded and fixed to a connection pin **550***a*. In similar fashion, the fixing piece **520***b* provided at the other end is also inserted into a corresponding installation hole **534***b* of the second insulating support member **530***b* and a projecting portion thereof from the installation hole **534***b* is welded and fixed to a connection pin **550***b*. The inverting dynode Dy**10** is also provided with fixing pieces Dy**10***a*, Dy**10***b* at its two ends. The fixing piece Dy**10***a* is inserted into a corresponding installation hole **533***a* of the first insulating support member **530***a* and a projecting portion thereof from the installation hole **533***a* is welded and fixed to a connection pin **550***a*. The fixing piece Dy**10***b* is inserted into a corresponding installation hole **533***b* of the second insulating support member **530***b* and a projecting portion thereof from the installation hole **533***b* is welded and fixed to a connection pin **550***b*. In addition, the light shied member **540** is attached to the first and second insulating support members **530***a*, **530***b* so as to surround the anode **520**. The anode **520** can become luminescent with increase in electron density. If such light from the anode **520** reaches the photocathode **230**, it will be reflected as noise component in the signal extracted from the anode **520**. Then, the light shield member **540** is installed so as to surround the anode **520**, whereby it functions to prevent the unwanted light from the anode **520** from reaching the photocathode **230**.

Each of the first and second insulating support members **530***a*, **530***b* is provided with projections **531***a*, **531***b* in the upper part (on the photocathode side). Each of the projections **531***a* of the first insulating support member **530***a* is inserted into an installation hole **511***a* of the focusing electrode disc **510**, while each of the projections **531***b* of the second insulating support member **530***b* is inserted into an installation hole **511***b* of the focusing electrode disc **510**. By this configuration, the focusing electrode disc **510** is fixed to the first and second insulating support members **530***a*, **530***b* grasping the dynode unit **550** including the anode **520**. Holes **512** provided in the focusing electrode disc **510** are holes for letting a lead pin **513** for supporting a metal material of the photocathode **230** which will be formed after the interior of the sealed container **100**A has become maintained in the vacuum state, pass through. The lead pin **513** is not used after formation of the photocathode **230**.

Through the above assembly process, each of the members constituting the electron multiplier unit **500**, such as the focusing electrode disc **510**, the first- to ninth-stage dynodes Dy**1**-Dy**9**, the anode **520**, the inverting dynode Dy**10**, and the light shield member **540**, is integrally and stably held by the first and second insulating support members **530***a*, **530***b*.

On the other hand, the stem portion **400** located opposite to the photocathode **230** with the electron multiplier unit **500** in between has the ceramic pedestal **410** to the center of which the exhaust tube **600** is attached and which holds the plurality of stem pins **430** arranged so as to surround the aperture of the exhaust tube **600**, and the metal reinforcement member **420** covering at least the side face of the ceramic pedestal **410**. The exhaust tube **600** is composed of the metal pipe **610**, and the glass pipe **620** fused and spliced to one end of the metal pipe **610**, and the glass pipe **620** is sealed after completion of evacuation for the interior of the sealed container **100**A (in the state in which the interior of the sealed container **100**A is maintained in the vacuum state).

In the stem portion **400**, the metal pipe **610** of the exhaust tube **600** is brazed and fixed to the ceramic pedestal **410** with the Ag—Cu alloy. In addition, the plurality of stem pins **430** are also brazed and fixed to the respective through holes of the ceramic pedestal **410** with the Ag—Cu alloy. Furthermore, the metal reinforcement member **420** is also brazed and fixed to the side face of the ceramic pedestal **410** with the Ag—Cu alloy. In addition, the other end of a corresponding one of the connection pins **550***a*, **550***b* is welded and fixed to each of the plurality of stem pins **430** each one of which is held in a penetrating state by the ceramic pedestal **410**.

Through the above assembly process, the electron multiplier unit **500** supported by the stem portion **400** through the connection pins **550***a*, **550***b* is obtained, as shown in FIG. **4**. As also seen from this FIG. **4**, the installation position and posture of the electron multiplier unit **500** in the sealed container **100**A are dependent on the lengths and welding positions of the connection pins **550***a*, **550***b* which directly connect the electron multiplier unit **500** and the stem portion **400**.

Next, the assembly processes of the head portion **200** and the body portion **300** each forming a part of the sealed container **100**A will be described in detail using FIGS. **5** and **6**. FIG. **5** is an assembly process diagram of the head portion **200** forming a part of the sealed container **100**A in the photomultiplier **100**. FIG. **6** is an assembly process diagram of the body portion **300** forming a part of the sealed container **100**A in the photomultiplier **100**.

The head portion **200**, as shown in FIG. **5**, is composed of the glass faceplate **210** and the Kovar flange **220**. The glass faceplate **210**, for example as shown in FIG. **2**, has the light entrance face **210***a* and the back face **210***b* which is a curved surface opposed to the light entrance face **210***a* and on which the photocathode **230** is formed. The Kovar flange **220** has a through hole for letting the photoelectrons from the photocathode **230** pass through and has an opening end face **220***a* directed toward the photocathode **230**, and an opening end face **220***b* directed toward the stem portion **400**. The glass faceplate **210** is fused and fixed to the opening end face **220***a* of the Kovar flange **220**, thereby obtaining the head portion **200**.

The body portion **300**, as shown in FIG. **6**, is composed of the Kovar flange **310**, the first ceramic side tube **330***a*, the fixing metal flange (fixing member) **320** for fixing of the focusing electrode disc **510**, the second ceramic side tube **330***b*, and the metal side tube **340** for fixing the stem portion **400** as a part of the sealed container **100**A while keeping the stem portion **400** inside, which are arranged in order from the photocathode **230** toward the stem portion **400**. The Kovar flange **310** has an aperture for defining the interior space of the sealed container **100**A and has an opening end face **310***a* directed toward the photocathode **230** and an opening end face **310***b* directed toward the stem portion **400**. The first ceramic side tube **330***a* also has an aperture for defining the interior space of the sealed container **100**A and has an opening end face **330***a***-1** directed toward the photocathode **230** and an opening end face **330***a***-2** directed toward the stem portion **400**. The fixing metal flange **320** has an inside end **320***a* located inside the sealed container **100**A and provided for defining a space for housing the focusing electrode disc **510**, and an outside end **320***b* surrounding the inside end **320***a*, and the outside end **320***b* has a flange face **320***b***-1** directed toward the photocathode **230** and a flange face **320***b***-2** directed toward the stem portion **400**. The second ceramic side tube **330***b* has an aperture for defining the interior space of the sealed container **100**A, and has an opening end face **330***b***-1** directed toward the photocathode **230** and an opening end face **330***b***-2** directed toward the stem portion **400**. The metal side tube **340** has an aperture for exposing the stem portion **400** into the interior space of the sealed container **100**A and has an opening end face **340***a* directed toward the photocathode **230**.

In the body portion **300** in FIG. **6**, the opening end face **310***b* of the Kovar flange **310** and the opening end face **330***a***-1** of the first ceramic side tube **330***a* are brazed and fixed with the Ag—Cu alloy. Furthermore, the opening end face **330***a***-2** of the first ceramic side tube **330***a* and the flange face **320***b***-1** (the flange face in the outside end **320***b* of the fixing metal flange **320**) are also brazed and fixed with the Ag—Cu alloy. The flange face **320***b***-2** (the flange face in the outside end **320***b* of the fixing metal flange **320**) and the opening end face **330***b***-1** of the second ceramic side tube **330***b* are also brazed and fixed with the Ag—Cu alloy. Furthermore, the opening end face **330***b***-2** of the second ceramic side tube **330***b* and the opening end face **340***a* of the metal side tube **340** are also brazed and fixed with the Ag—Cu alloy. By this configuration, the outside end **320***b* of the fixing metal flange **320** is grasped by the first and second ceramic side tubes **330***a*, **330***b* and the fixing metal flange **320** is fixed to the sealed container **100**A (the fixing metal flange **320** itself forms a part of the sealed container **100**A).

The focusing electrode disc **510** fixed to the fixing metal flange **320** shown in FIG. **6** has the structure as shown in FIG. **7**. FIG. **7** shows a development view of the focusing electrode disc **510** forming a part of the electron multiplier unit **500**. FIG. **8** shows a development view of the fixing metal flange **320** for fixing the position of the electron multiplier unit **500** relative to the sealed container **100**A by fixing the focusing electrode disc **510** of the electron multiplier unit **500**.

As shown in the development view (top plan view and side view) of FIG. **7**, the focusing electrode disc **510** is provided with the aperture **510***a* for letting the photoelectrons from the photocathode **230** pass through, the installation holes **511***a* in which the projections **531***a* provided on the first insulating support member **530***a* are inserted, the installation holes **511***b* in which the projections **531***b* provided on the second insulating support member **530***b* are inserted, and the holes **512** for the lead pin **513** for supporting the metal material for formation of the photocathode **230**, to pass through. The aperture **510***a* is covered by a mesh electrode. Portions indicated by A1, in the outer periphery of the focusing electrode disc **510**, are welded and fixed to the inside end **320***a* of the fixing metal flange **320**.

As shown in the development view (side view, top plan view, and bottom plan view) of FIG. **8**, the fixing metal flange **320** has the inside end **320***a* located inside the sealed container **100**A and extending toward the photocathode **230**, and the outside end **320***b* surrounding the inside end **320***a*. The inside end **320***a* defines the aperture **321** for housing the focusing electrode disc **510** and portions indicated by B1 are

welded and fixed to the focusing electrode disc **510**. The outside end **320***b* has the flange face **320-1** brazed and fixed to the opening end face **330***a***-2** of the first ceramic side tube **330***a* and the flange face **320***b***-2** brazed and fixed to the opening end face **330***b***-1** of the second ceramic side tube **330***b*, thereby to be grasped by the first and second ceramic side tubes **330***a*, **330***b*. The fixing metal flange **320** is provided with a plurality of through holes **322** so as to surround the first tube axis AX1 of the sealed container **100**A, at portions located between the inside end **320***a* and the outside end **320***b* and in the interior space of the sealed container **100**A.

Each of the plurality of through holes **322** establishes communication between the two spaces separated by the focusing electrode disc **510** and the fixing metal flange **320**, i.e., between the space where the dynode unit **550** exists and the space where the photocathode **230** exists. The anode **520** can possibly become luminescent with increase in electron density. The light generated in the anode **520** is blocked to some extent by the light shield member **540** but it cannot be said enough. If the light from the anode **520** leaking from the electron multiplier unit **500** reaches the photocathode **230**, it will be reflected as noise component in the signal extracted from the anode **520**. On the other hand, the photocathode **230** is formed by supplying the alkali metal vapor from the stem portion **400** side toward the photocathode **230** side, and thus it is necessary to provide a gap in some width between the body portion **300** and the electron multiplier unit **500** in the sealed container **100**A in the vacuum state. Then, the fixing metal flange **320** in the present embodiment is provided with the plurality of through holes **322**.

The below will describe a process for finally manufacturing the photomultiplier **100** of the present embodiment with the sectional structure shown in FIGS. **1** and **2**, by fixing the parts assembled as described above (FIGS. **4** to **6**), in close contact, using FIGS. **9** and **10**. FIG. **9** is a drawing (part 1) for explaining the final assembly process of the photomultiplier **100**, which is a cross-sectional view coincident with the cross section of the electron multiplier unit along the line I-I in FIG. **4**, the cross section of the head portion along the line II-II in FIG. **5**, and the cross section of the body portion along the line III-III in FIG. **6**. FIG. **10** is a drawing (part 2) for explaining the final assembly process of the photomultiplier **100**, which is a cross-sectional view coincident with the cross section of the electron multiplier unit along the line I-I in FIG. **4**, the cross section of the head portion along the line II-II in FIG. **5**, and the cross section of the body portion along the line III-III in FIG. **6**.

First, the electron multiplier unit **500** and the stem portion **400** (internal unit) obtained through the assembly process in FIG. **3** are fixed to the body portion **300** obtained through the assembly process in FIG. **6** and, thereafter, the head portion **200** obtained through the assembly process in FIG. **5** is fixed to the body portion **300**.

The fixing of the electron multiplier unit **500** and the stem portion **400** to the body portion **300** is carried out in a state in which the electron multiplier unit **500** supported by the stem portion **400** through the connection pins **550***a*, **550***b* is inserted in the body portion **300**, as shown in FIG. **9**. First, at portions indicated by arrows C in FIG. **10**, the focusing electrode disc **510** of the electron multiplier unit **500** is welded and fixed to the inside end **320***a* of the fixing metal flange **320** of the body portion **300**. Subsequently, the stem portion **400** is set in the metal side tube **340** of the body portion **300** and then, at portions indicated by arrows D in

FIG. **10**, the metal reinforcement member **420** of the stem portion **400** is welded and fixed to the metal side tube **340**.

Furthermore, as shown in FIG. **10**, the body portion **300** (the opening end face **310***a* of the Kovar flange **310**) to which each of the electron multiplier unit **500** and the stem portion **400** is welded and fixed) is welded and fixed to the head portion **200** (the opening end face **220***b* of the Kovar flange **220**), thereby obtaining the photomultiplier **100** of the present embodiment shown in FIG. **2**.

It is noted that no change is allowed for the order of welding and fixing the electron multiplier unit **500** and the stem portion **400** to the body portion **300**. This is attributed to the step (FIG. **3**) of fixing the electron multiplier unit **500** to the stem portion **400** through the connection pins **550***a*, **550***b*. Namely, as shown in FIG. **11**, the distance between the focusing electrode disc **510** and the stem portion **400** (ceramic pedestal **410**) generally varies depending upon the welding positions between the electrodes in the electron multiplier unit **500** and the connection pins **550***a*, **550***b* and the welding positions between the stem pins **430** and the connection pins **550***a*, **550***b*, as well as the lengths of the connection pins **550***a*, **550***b*. In the case of FIG. **11**, the left internal unit has the distance L1 between the focusing electrode disc **510** and the stem portion **400** and the right internal unit has the distance L2 between the focusing electrode disc **510** and the stem portion **400**, producing a difference ΔL between the manufactured internal units. If under such circumstances of occurrence of such size variation among manufactured internal units the focusing electrode disc **510** is welded and fixed to the fixing metal flange **320** of the body portion **300**, it will result in variation in relative position of the stem portion **400** to the second ceramic side tube **330***b* of the body portion **300**.

In the present embodiment, for solving the problem in manufacture associated with the fixing of the installation position of the focusing electrode disc **510**, the metal side tube **340** is provided on the opening end face **330***b*-**2** side of the second ceramic side tube **330***b*. Since this metal side tube **340** has the space for housing the stem portion **400** as shown in FIG. **12**, it can absorb the size variation among manufactured internal units.

The photomultiplier **100** with the structure as described above can be applied to various sensor modules used under high-temperature, high-pressure environments, e.g., in underground resource exploration. As an example, FIG. **13** is a drawing for explaining an assembly process of a sensor module according to an embodiment of the present invention. FIG. **14** is a drawing showing a sectional structure along the line IV-IV in FIG. **13**, of the sensor module according to the present embodiment.

In FIG. **13**, the sensor module **700** has the photomultiplier **100**, a metal case (SUS case) **710**, an insulating case **720**, a positioning spacer (posture adjustment member) **730**, a socket **740**, and a back lid **750**. The metal case **710** is a hollow member extending along the tube axis AX2 (second tube axis) and is provided with openings **710***a*, **710***b* at two ends thereof. The insulating case **720** has a through hole **720***a* for protecting the body portion **300** of the photomultiplier **100**. The positioning spacer **730** has a taper face **730***a* with which the photomultiplier **100** is brought into contact, and a through hole **730***b* for letting the stem pins **430** extending from the photomultiplier **100**, pass through. The socket **740** has a plurality of holes and the stem pins **430** are set in these holes, whereby the socket **740** is attached to the photomultiplier **100**. The socket **740** has a cable **740***a* electrically connected to these stem pins **430**. The back lid **750** has a through hole **750***a* for taking the cable **740***a* extending from the socket **740**, out to the outside of the metal case **710**, and is attached to an opening end of the aperture **710***b* of the metal case **710**.

The sensor module **700** shown in FIG. **14** is obtained through the above assembly process. In the sensor module **700** in FIG. **14**, a two-part silicone encapsulant **760** is filled in a gap between the inner wall of the metal case **710** and the head portion **200** of the photomultiplier **100**.

Next, control of the posture of the photomultiplier **100** in the sensor module **700** according to the present embodiment (a method of installing the photomultiplier **100** in the metal case **710**) will be described using FIGS. **15** and **16**. FIG. **15** is a drawing for explaining the relationship between the first tube axis AX1 of the photomultiplier **100** and the light entrance face **210***a* of the glass faceplate **210** forming a part of the head portion **200**. FIG. **16** is a drawing for explaining the control of the posture of the photomultiplier **100**, as technical effect of the sensor module **700**.

The head portion **200** of the photomultiplier **100** housed in the metal case **710** is composed of the glass faceplate **210** and the Kovar flange **220** and, normally, the light entrance face **210***a* of the glass faceplate **210** can be inclined at angle θ to the first tube axis AX1 of the sealed container **100**A, as shown in FIG. **15**. If this photomultiplier **100** is set in the metal case **710** with the first tube axis AX1 (the tube axis of the sealed container) being aligned with the second tube axis AX2 (the tube axis of the metal case), the light entrance face **210***a* will be also inclined relative to the opening end face (aperture **710***a* side) of the metal case **710**, raising a possibility of failing to ensure sufficient durability.

In the present embodiment, therefore, the positioning spacer **730** is arranged in the metal case **710** and between the housed photomultiplier **100** and the socket **740**. This positioning spacer **730** has the taper face **730***a* with which the stem portion **400** of the photomultiplier **100** is brought into contact, and can function to maintain the posture of the photomultiplier **100** in the metal case **710**. Namely, the photomultiplier **100** is brought into contact with the taper face **730***a* of the positioning spacer **730**, whereby the posture of the photomultiplier **100** can be kept stable, in a state in which the first tube axis AX1 and the second tube axis AX2 are out of alignment so as to keep the light entrance face **210***a* of the glass faceplate **210** and the opening face (aperture **710***a*) of the metal case **710** parallel to each other. As a result, we obtain the sensor module **700** with sufficient durability ensured and with excellent anti-vibration performance.

As described above, the photomultiplier according to the present embodiment realizes the structure resistant to use under high-temperature, high-pressure environments and the anti-vibration performance thereof is drastically improved when compared with the conventional technology. Furthermore, the sensor module according to the present embodiment also allows the posture of the photomultiplier to be kept stable in the case and the anti-vibration performance thereof is drastically improved when compared with the conventional technology.

From the above description of the present invention, it will be obvious that the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the present invention, and all improvements as would be obvious to those skilled in the art are intended for inclusion within the scope of the following claims.

What is claimed is:

1. A photomultiplier comprising:

a sealed container the interior of which is maintained in a vacuum state, the sealed container including a first ceramic side tube and a second ceramic side tube arranged in order along a first tube axis of the sealed container;

a photocathode housed in the sealed container and configured to emit photoelectrons into the sealed container in response to light of a predetermined wavelength;

an electron multiplier unit housed in the sealed container, the electron multiplier unit comprising: a dynode unit including multi-stage dynodes to emit secondary electrons in response to the photoelectrons arriving from the photocathode and successively cascade-multiply the secondary electrons; an anode for extracting as a signal, secondary electrons resulting from cascade multiplication by the dynode unit; a pair of insulating support members for integrally holding the dynode unit and the anode, while grasping the dynode unit and the anode; and a focusing electrode arranged between the photocathode and the dynode unit while being fixed to the pair of insulating support members, the focusing electrode having a through hole for letting the photoelectrons from the photocathode pass through; and

a fixing member separated from the focusing electrode and having an aperture for defining an installation position of the focusing electrode, an inside end defining the aperture, and an outside end surrounding the inside end, the fixing member being fixed to the sealed container so that the outside end is grasped by the first ceramic side tube and the second ceramic side tube, while the inside end located in the sealed container is fixed to the focusing electrode,

wherein the inside end has a shape that extends toward the photocathode, and an outer periphery of the focusing electrode is fixed to the inside end while the focusing electrode is housed in the inside end.

2. The photomultiplier according to claim **1**, wherein the sealed container further comprises:

a stem portion comprised of a ceramic pedestal for, with a plurality of stem pins penetrating through, holding the plurality of stem pins, and a metal reinforcement member covering at least a side face of the ceramic pedestal; and

a metal side tube having an aperture for defining an installation position of the stem portion, the metal side tube being located opposite to the first ceramic side tube with the second ceramic side tube in between, one end of the metal side tube being fixed to the second ceramic side tube, and

wherein the metal reinforcement member of the stem portion is fixed to the metal side tube.

3. The photomultiplier according to claim **1**, wherein the fixing member has a plurality of through holes provided between the inside end and the outside end, each of the plurality of through holes establishing communication between a space where the dynode unit exists and a space where the photocathode exists.

4. The photomultiplier according to claim **3**, wherein the plurality of through holes of the fixing member are arranged so as to surround the first tube axis of the sealed container.

5. A sensor module comprising:

the photomultiplier as set forth in claim **1**; and

a case for housing the photomultiplier, the case having openings at two ends thereof and having a shape extending along a second tube axis.

6. The sensor module according to claim **5**, further comprising a positioning spacer for defining an installation position of the photomultiplier in the case, the positioning spacer being installed in the case.

7. The sensor module according to claim **6**, wherein the positioning spacer has a taper face with which a part of the photomultiplier is in contact.

8. The sensor module according to claim **7**, wherein the photomultiplier is housed in the case, in a state in which the first tube axis of the sealed container and the second tube axis of the case are out of alignment.

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